High resolution MSI-guided multiple monophasic action potential mapping with a single amagnetic catheter

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1 Introduction

During recent years, catheter ablation has become a method of choice in definitive treatment of cardiac arrhythmias. Prerequisite for successful ablation is the precise localization of the arrhythmogenic substrate underlying the clinical arrhythmia. This is usually done during invasive electrophysiological study (EPS) with multichannel endocardial mapping under fluoroscopic imaging [1,2]. More recently new nonfluoroscopic methods for three-dimensional (3D) localization of electrocatheters position and electro-anatomical integration of local endocardial activation time, which use externally applied magnetic or electric fields, are under clinical evaluation [3,4]. The major limitation of all the above methods is that they cannot be use to provide information preoperatively, nor to investigate focal arrhythmogenic mechanisms. On the contrary Cardio Magnetic Source Imaging (CMSI) [5] is the unique method for preoperative non invasive 3D localization of arrhythmias, which provides also nonfluoroscopic 3D localization of an amagnetic electrocatheter (AC) [6-9]. The improved amagnetic electrocatheter [10], by virtue of the peculiar configuration thereof and of the nature of the materials used for the construction thereof, is suitable for single-catheter multiple monophasic action potential recording (Multi-MAP function), although being localizable by surface CMSI, with high spatial resolution and without fluoroscopy.

2 Methods

2.1 CMSI-guided MultiMAP recording and ablation

The special geometry of the new Multi-MAP AC permits a highly accurate three-dimensional localization of the distal end (tip) of the catheter by CMSI, visualizing the positioning thereof almost in real time inside a three-dimensional model of the heart of the patient under examination, interactively analyzable by the operator. This permits to drive the catheter, by a numerical spatial control of the distal end thereof, until the three-dimensional coordinates fit at the best those of the arrhythmogenic area, with minimum use of fluoroscopy.

The CMSI driving method of the catheter onto the arrhythmogenic substrate is carried out as follows.

- Prior to the invasive EPS, a magnetocardiographic (MCG) study of the patient is carried out in order to assess, even by reiterated mapping, the characteristics of the magnetic field generated by the arrhythmogenic structure susceptible of catheter ablation, and its reproducible 3D localization thereof.
- On the basis of such preoperative information, the Multi-MAP AC is driven under fluoroscopic control in close proximity of the presumably arrhythmogenic area. Then the catheter is repositioned under CMSI spatial control, until the 3D coordinates of the distal end thereof fit at the best those of the target arrhythmogenic area.
- Upon reaching the presumed arrhythmogenic area, single-catheter multiple MAP recording provides the estimate of the local repolarization scattering; of the local conduction speed; of the route of the depolarization front. Furthermore Multi-MAP recording can identify afterpotentials or areas of focal block, with or without micro re-entry.
- Once the arrhythmogenic nature of the substrate under examination has been confirmed, ablation energy can be outputted. For this purpose a special version of the MultiMAP AC is provided with coaxial fiberoptics, centered with respect to the area defined by the MAP recording. This allows modifying the electrogenesis of the underlying myocardium, monitoring the effects thereof according to the aforesaid parameters and to the characteristics of the arrhythmia under examination [10].

In case the effectiveness of a functional exclusion of the substrate under examination has been documented, this can be effectively ablated with a suitable energy output. Hence, the CMSI-guided MultiMAP method is aimed at the implementation of an entirely innovative approach to the EPS and to the ablation of the cardiac arrhythmias, with high spatial resolution and minimal invasivity.

By virtue of their characteristics, the variants of the electrocatheter according to the invention are localizable by MCG mapping, at the same time being apt to record multiple MAPs, to implement intracardiac stimulation (pacing) and to output energy by laser emission.

2.2 Patients

Fifteen patients, all undergoing EPS for supraventricular arrhythmias, have been studied so far with a 6F amagnetic MultiMAP catheter, inserted in the heart during routine EPS, after written informed consent.

In the first 10 patients the procedure was aimed to validate the accuracy of MCG and BSP mapping studies for locating non-invasively the position of an artificial current-dipole source inside the heart generated at the tip of the AC and during the local cardiac response evoked by the stimulus. The catheter positions recorded on fluoroscopic X-ray images provided the golden standard for the non-invasive dipole localization [6-9].

In the last 5 patients, presented in this paper the MultiMAP method was added to EP investigation to evaluate whether it could provide information about focal arrhythmogenic mechanism, undetected with conventional catheters. One (4 pts) or two (1 pt). MultiMAP catheters were used for high resolution MAP mapping from at least two different sites of right atrium. Four MAPs were recorded with each catheter, from an area of 3.5 mm^2.

MAP signals were differentially amplified, bandpass filtered (DC-500 Hz) and digitized at the sampling frequency of 1 kHz, using a *Prucka Engineering* polygraph for electrophysiology (version 4.10).

In all patients MultiMAP recording was performed during sinus rhythm, under decremental atrial pacing at three cycle lengths (600, 400 and 320 ms) for one minute, and during premature atrial stimulation at three drive cycle lengths (600, 400 and 320 ms). MAP duration was calculated at 50% and 90% of repolarization. Local activation time was calculated between the phase 0 of the MAPs. Care was paid to evidence repolarization inhomogeneity and focal block.

3 Results

In all five patients, good quality MAP recording was obtained from the right atrium. However in one case the MAP morphology was distorted during local atrial pacing performed with the MultiMAP catheter. Local atrial block undetected by conventional atrial mapping was evidenced in 2/5 patients. An example of double catheter MultiMAP recording is seen in Fig. 1. The patient had recurrent episodes of sustained iterative atrial tachyarrhythmia.

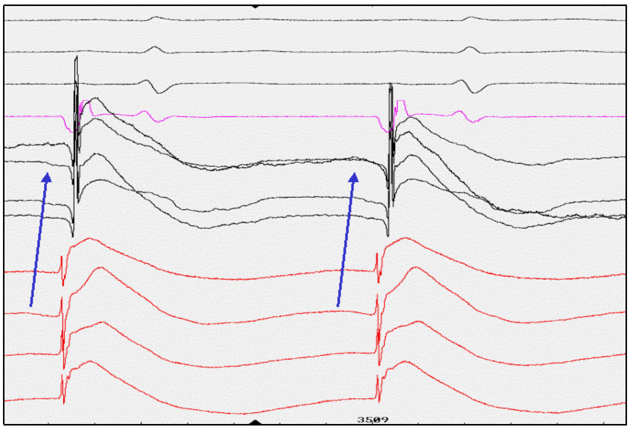

Figure 1: *Example of high resolution mapping with two MultiMAP amagnetic catheter in one patient with recurrent episodes of sustained iterative atrial tachyarrhythmia. The different morphology and duration of the MAP recorded by the 2 catheters is evident, being the lower 4MAP (red) of "slow" type. The sequence of local activation, during sinus rhythm is indicated by the blue arrows.*

Two MultiMAP catheters were placed, about 1 cm apart, at the high free wall of the right atrium, where the earliest activation was recorded during atrial tachycardia. Local atrial block and a single atrial echo beat were inducible with a single premature stimulus with coupling interval of 220 ms, at a drive cycle length of 600 ms (Fig. 2 and Fig. 3), whereas local atrial block and sustained atrial tachycardia (cycle length of 180 ms) were induced with a premature stimulus with coupling interval of 200 ms (Fig. 4 and Fig. 5). Local atrial block occurred at an area where MAP morphology was of the "slow" type. MultiMAP recording evidenced very clearly the local block and the inversion of the activation sequence between the two MAP recording sites (Fig. 3 and Fig. 5). This abnormality was not detectable on filtered electrograms recorded with a multielectrode Halo catheter.

The MultiMAP catheter was accurately localizable with CMSI, but not with BSPM [7].

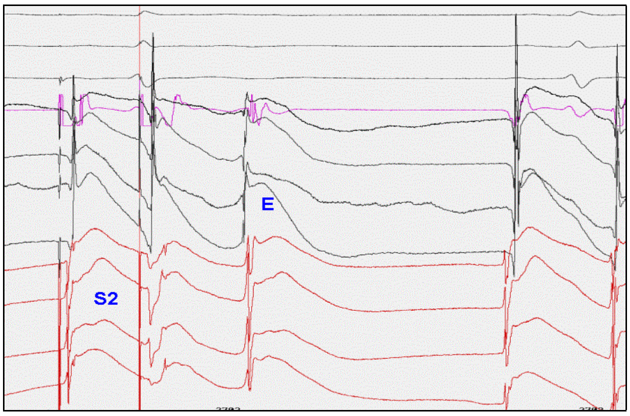

Figure 2*: same patient as in Fig. 1. A premature atrial stimulus (S2), coupling interval 220 ms at a drive cycle length of 600 ms, induces local atrial block and a single echo beat (E) .*

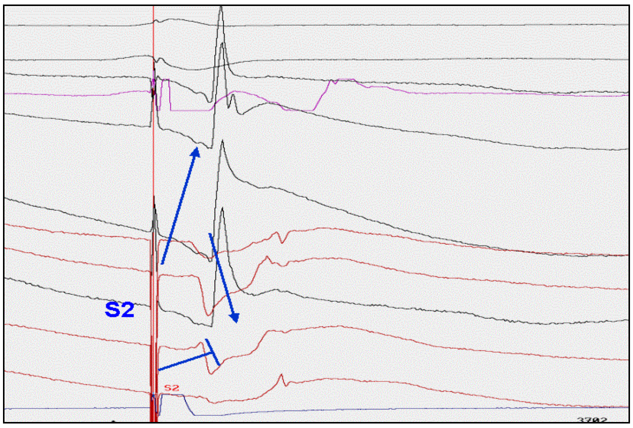

Figure 3: *Time resolution enhancement of the second beat in Fig. 2, which evidence the area of local atrial block and the depolarization sequence of the premature (S2) beat.*

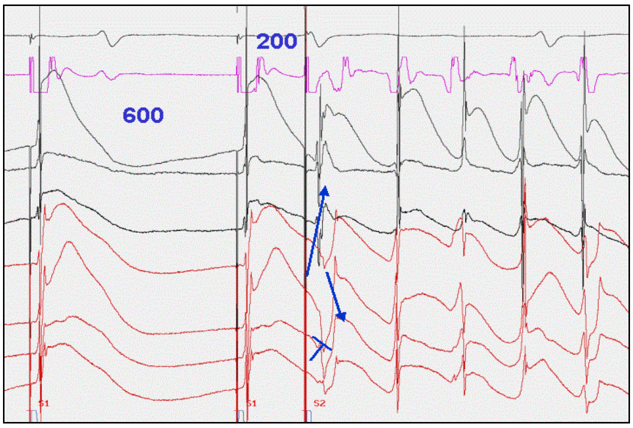

Figure 4: *Same patient as in Fig. 1. A more premature atrial stimulus (coupling 200 ms) at the same drive cycle length of 600 ms, induces local atrial block with sustined atrial tachyarrhythmia.*

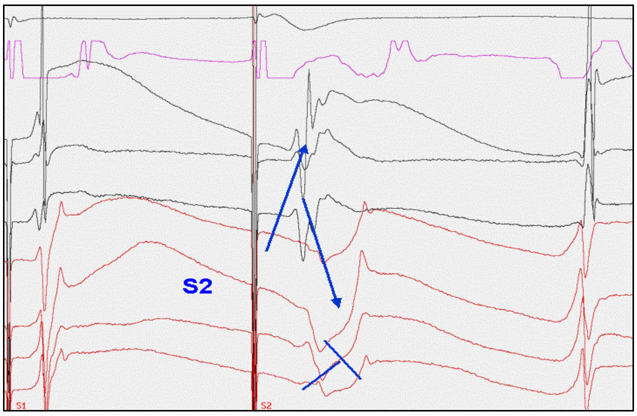

Figure 5: *Time resolution enhancement of Fig. 4, which evidence the area of local atrial block and the depolarization sequence of basal (S1), premature (S2) and of the first beat of sustained atrial tachycardia.*

4 Discussion

The new MultiMAP amagnetic catheter presented in this paper is the evolution of those used in previous investigations to test the accuracy of MCG mapping for non invasive 3D localization of intracardiac sources [12,13].

In this study the new MultiMAP catheter was tested to verify whether or not it could be effectively used for sophisticated high resolution MAP mapping without further complication of its design to gather new clinically EP information. Also the quality of the MAP recordings was good, some modification have been necessary to improve the stability of the catheter and of MAP morphology during atrial tachyarrhythmias. Although the number of investigated patients in still limited, focal atrial block with reentry in the area of ectopic earliest activation during tachycardia was evidenced by MultiMAP recording only. Interestingly this block occurred at a site where “slow type” MAPs were recorded.

The localization accuracy of the amagnetic MultiMAP catheter has been recently demonstrated [6-9]. In patients it ranges from about 5 to 25 mm, depending mainly on the signal-to-noise ratio of the measurement. However most of the catheter 3D localizations were precise better than 5 mm, expecially when the respective localization of two catheters was calculated, which minimized errors due to respiratory and cardiac movements.

This means that CMSI of MultiMAP catheters is valuable for providing advance electroanatomical integration of electrophysiological information to select patients susceptible of successful ablative treatment on a more objective basis, especially

patients with focal arrhythmias, which localization can be coumbersome during catheterization. However, it is still difficult to combine the inverse solutions accurately with cardiac anatomy. Movement of the chest and the heart complicates this registration problem, particularly if the MCG and MRI sessions are not performed during the same day. More advanced methods need still to be developed for accurate integration of the CMSI results with the cardiac anatomy and data gained during invasive EPS. A 3D flexible model of the heart, to be tailored to the individual patient using his 2D fluoroscopic imaging and echocardiographic data, seems to be the most cost/effective approach.
Indeed electroanatomical integration can be nowaday achieved with other methods like e.g. CARTO^{TM} [3] or LocaLisa [4]., which seem to be even more precise than CMSI [4,7]. However a major limitation of all those methods is that they can be used during invasive procedure only and cannot provide any preoperative information about the localization of the arrhythmogenic substrate. On the other hand although BSPM could be used to attempt non invasive preoperative localization of the arrhythmogenic area, its 3D accuracy was definely poorer when compared with MCG mapping using an amagnetic catheter as test intracardiac source [7].

Acknowledgements

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